TECHNICAL NOTES

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No. 753

# MEASUREMENT OF THE FORCES ACTING ON GLIDERS IN TOWED FLIGHT

By W. B. Klemperer
The Soaring Society of America, Inc.



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## SUMMARY

The magnitude, the direction, and the fluctuations of tow forces exerted upon gliders by towing them aloft behind an automobile were measured under a variety of conditions covering a range from gentle to severe types of operation. For these tests, the glider towing force did not exceed 1.6 of the gross weight of the glider. V-G records obtained during the towed-flight period as well as during the subsequent return glide to earth showed accelerations in the range from 3 g to -1 g. The results of preliminary airplane tow tests are also presented.


## INTRODUCTION

While gliders and sailplanes in free flight are exposed to air-load conditions similar to those of powered airplanes, a different category of load is introduced in towed flight. The towing of engineless aircraft has developed into an established technique for the purpose of (1) launching them into the air to a point from which they can glide down in training hops, (2) launching them into the air so that they can continue to soar in favorable air currents, or (3) ferrying them to a destination. Towing is effected usually by automobile, motorboat, winch, or powered aircraft. The tow force being an extraneous force, it can assume magnitudes and directions independent of the flight attitude of the towed craft. If excessive, it may surpass the design allowance for such a force for either craft. In the earlier days of towing, some accidents were actually attributed to excessive tow forces. It is therefore necessary for design use to establish reasonable limits of the tow forces that engineless aircraft may encounter in service.

It has been recognized that the towing forces and the loads which they can impose on the glider structure depend greatly on the towing method and technique. Statistical

data on these forces under a variety of conditions are therefore a requisite for establishing practical design requirements.

Reference 1 describes a tow-force recorder built into a towing pole mounted on a high-performance sailplane ("Austria," weight 1,070 lb.) with a maximum accelerating force of 360 pounds, a maximum tow-force peak in flight of 200 pounds, and an average of 110 pounds. The use of a camera obscura for investigations into the climb of sailplanes in auto tow is also described.

Reference 2 gave samples of tow-force records of auto tow climbs of a primary glider ("Zögling," weight 340 lb.) without wheels exhibiting sharp oscillations of a frequency of the order of 2 seconds and reaching peaks of 250 pounds in the hands of the instructor and of 450 to 600 pounds in the hands of the students. A sailplane ("Fasold," weight 650 lb.) reached 300 and 450 pounds in auto or winch tow and but 225 pounds in aircraft tow.

Weak links were suggested in reference 3 for use in winch towing of gliders to be designed to fail at 700 to 800 pounds.

In order to confirm and supplement these tests, a program of tow tests under conditions meant to cover the varieties of American glider operation practice was instituted in 1937, under the sponsorship of the National Advisory Committee for Aeronautics upon the recommendation of the then Bureau of Air Commerce, and was carried out by groups affiliated with the Soaring Society of America. The present note is a report on these tests.

The auto-towed-glider tests were divided into two groups. The first group of tests comprises 16 test flights with a "Cadet" type of glider, all by one very experienced pilot on a busy and limited airport at Akron, Ohio, under a variety of wind conditions and piloting techniques to simulate both good and bad practices. This group of tests was conducted by the Akron Glider Council under the direction of J. Funk and H. Funk on October 30, 1937.

The second group of tests covers 8 test flights on a "Salvfuglen" type of glider by several pilots of varied experience on a desert dry lake bed (Muroc Dry Lake), the vast, flat, and smooth terrain of which lent itself ideally

to towing for many miles and to a training routine. This group of tests was conducted by members of the Southern California Soaring Association under the direction of V. Jensen in August and September 1938.

In order to gain some preliminary information on the tow forces in aircraft tow and some clues regarding measuring technique for aircraft tow, which differs somewhat from auto tow, a third group of tests consisting of two test flights were conducted on May 21, 1939. These flights were made at the Compton, California, airport on a "Briegleb" Utility type of glider. Towing-force measurements were obtained in straight climbing flight.

## I - AUTOMOBILE TOWED TESTS AT AKRON, OHIO

### Equipment

The glider used in the first group of tests was a Cadet of the Secondary Training or General Utility type, a high-wing monoplane, license No. G10265, owned by Richard Randolph of Akron, Ohio. It was constructed as shown on the attached photograph (fig. 1) except that jury struts and additional tail-bracing wires were provided (as authorized by the Bureau of Air Commerce). The wing span of the glider was 37 feet 10 inches; length, 18 feet 9 inches; wing area, 160 square feet. The weights were as follows:

| | Pounds |
|---|---|
| Weight empty. . . . . . . | 296 |
| Instruments . . . . . . . | 28 |
| Pilot . . . . . . . . . . | 160 |
| Towline . . . . . . . . . | 15 |
| Total weight, loaded. . . | 499 |

The towing hook was in the nose of the fuselage, 67 inches ahead of the center of gravity. The towline consisted of 1,000 feet of new No. 15 gage black Premier steel wire of 1,000 to 1,400 pounds breaking strength

weighing approximately 15 pounds. The top end of the line was made of approximately 6 feet of 7x7 by 1/8 inch flexible steel cable. At the bottom of the towline, a short loop of rope was slung over the rear bumper of the tow car to serve as a snubber. The tow car was a 1937 Ford V 8 driven by Ralph Goodman, a very experienced tow-car driver and himself a soaring pilot.

The following special instruments were carried aboard the glider during the tests:

(a) A Goodyear Zeppelin type of cable tensiometer shown in figure 2 attached to the cable at the nose of the fuselage. It was calibrated prior to the tests.

(b) A motion-picture camera mounted on an outrigger protruding forward from the junctures of the left wing struts and jury struts 28 inches ahead of the leading edge. (See fig. 3.) It photographed the tensiometer in flight; the pictures also show the angle between the tow cable and the ship.

(c) An N.A.C.A. V-G recorder.

(d) A combined N.A.C.A. electrically recording air-speed meter and statoscope were carried in the bottom of the fuselage just below the center of gravity. The pitot tubes of the N.A.C.A. instruments were mounted on the camera outrigger 26 inches ahead of the camera.

(e) Regular dashboard instruments comprised an altimeter, an air-speed meter, and a rate-of-climb indicator.

The instrument arrangement can be seen on figure 4.

## Method

The take-offs were made along the edge of the Municipal Airport at Akron, Ohio. The paths on which the car traveled were somewhat rough but not excessively so.

All flights were made on October 30, 1937, between 9:30 a.m. and 4:30 p.m. Wind speed and direction were

measured at the take-off point on a pole approximately 8 feet above the ground immediately prior to each tow. These observations are listed on table I. All tows were made against a quartering cross wind. During flights 2, 3, and 4, the wind was WNW and the towing direction was N. During all other flights, the wind was W and the towing direction SW. The glider could not be towed directly into the wind because air traffic using the surfaced runways of the airport forced the glider operations to be conducted along the port boundaries. The air was notably rough on flight 2.

The glider was piloted by Richard W. Randolph, a very skilled glider pilot of considerable experience in all types of soaring and acrobatics but with very limited power plane experience. He climbed at various rates from very gentle to steeper than standard practice. On some flights, he deliberately simulated various typical piloting errors or special maneuvers such as failure to damp porpoising and excessive yawing, as mentioned in table I.

Some of the maneuvers were repeated either because not all instruments had been in operation or in order to gain statistical material on variations likely to occur unintentionally.

The tow forces were read off the motion picture films in an editoring projector frame by frame; some of the results are plotted in figure 5. The camera speed was approximately 24 frames per second. The accuracy of the tensiometer readings is approximately 5 percent. The highest tow forces observed were 800 pounds.

The towline angle $\alpha$ was also read off the motion picture films and corrected for the perspective of the camera axis. Owing to the skew camera mount, the angle appears ($\alpha'$) less steep than it really was ($\alpha$). The error based on the relation $\tan \alpha = \tan \alpha'/\cos 25^\circ$ amounts to $3^\circ$ when the apparent angle is $45^\circ$ and less when the angle is larger or smaller ($2^\circ$ at $20^\circ$ or $70^\circ$). The accurate canting angle of the camera mount with respect to a reference line on the airplane was lost but there is evidence that the camera frame was nearly parallel to the wing chord, probably within $2^\circ$. The corrected angle ($\alpha$) is therefore presumably the angle between cable and wing chord $\pm 2^\circ$. This angle is plotted in figure 5 against picture frame number (time). For flights 1, 6, and 9, both the angle as it appeared on the film and the corrected angle are plotted. The steepest angle attained was $72^\circ$ at the peak of an excessive oscil-

lation, at which time the tow cable actually became slack and the cable obviously sagged aft.

The velocity head q can be read off the film from the N.A.C.A. recorder (fig. 6), according to a calibration diagram prepared by the N.A.C.A. An attempt was made to transpose the record of q in inches of water (with a miles per hour scale) to the other charts (fig. 5) for flights 2 and 12. The identification of time, however, was not accurately accomplished. (The original plan of coding the start and stop of the camera on the electric recorder was not carried out; it was also difficult for the pilot to ascertain the instant when the camera stopped.) Several of the records, however, show quite definitely the instant of release of the towline and, the recorder film speed (one turn of the drum in 165 seconds) being known, the air-speed history could be reasonably well reconstructed. The N.A.C.A. traces seem to cover more time than the motion picture films. To what extent this discrepancy was due to the camera's running more slowly than measured and to what extent to a time interval in starting the instruments could not be reconstructed. The maximum air speed observed was 70 miles per hour.

Identification of the time scale was similarly obscured for the statoscope records. The fastest rate of climb recorded was of the order of 7 meters per second (almost 1,400 feet per minute).

The V-G records could not be synchronized with the other measurements. Most of the appreciable accelerations recorded probably occurred during flight maneuvers after release, with the possible exception of the most violent "porpoising" cycles. Accelerations recorded at low velocities were undoubtedly merely landing shocks.

## Results and Discussion

Towing forces.- The maximum towline forces observed in these tests are of the order of 800 pounds, or 1.6 times the gross weight of the glider. This maximum, however, was reached or approached in deliberately steep climbs that were admittedly more severe than those recommended for normal practice. The value may be considered as extreme, although there is, of course, no guaranty that higher loads cannot be reached, for instance, by driving the tow car faster or against a stronger head wind. There

is, however, no reasonable incentive to do this under "normal" operating conditions.

The highest tow-force component normal to the wing chord, as evaluated from the tow force times the sine of the corrected towline angle, that ever occurred during the tests is of the order of 550 pounds (1.1 gross weight). This value was attained on flight 9 and almost reached on flights 4, 5, and 6, which were the steepest climbs; on the other flights, the normal force stayed considerably lower and rarely exceeded 400 pounds (80 percent of gross weight).

The rate of climb noted during the phases of largest normal forces was of the order of 1,000-1,400 feet per minute, but it may be noted that forces nearly as high are reached toward the end of a tow when the line is steep and the rate of climb is no longer large.

<u>Porpoising</u>.- Certain gliders, especially those having the tow hook far forward, exhibit a tendency to perform pitching oscillations when climbed steeply or when a steep angle of the towline is reached. This motion is known as "porpoising." A skilled pilot can readily damp it either by easing up on the towline angle or by suitably timed elevator maneuvers. The mechanism of porpoising is perhaps not fully understood; but a theory has been advanced that it is due to stalling of the empennage, which has to balance the strong diving moment of the towline pulling down on the fuselage nose. This diving moment can be much greater than any ever experienced in free flight.

The phase relationship between simultaneous oscillations of the towline angle and of the tow force, as shown by the present motion-picture records, would not contradict this theory. The peaks of the angle and the tow-force fluctuations often nearly coincide, the maximum force often lags a fraction of a second behind the maximum angle. The frequency of the oscillations was mostly of the order of one second (from 3/4 to 1-1/2 seconds). Flight 6 is the outstanding example, with oscillations of the tow force as sudden as from 700 pounds to completely slack in less than one-half second. It must be remembered that the cable-to-chord angle does not vary exactly like the true angle of attack because the sag of the cable due to its own drag and weight appreciably increases as the tow load slackens. There were at least three instances on flight 6 (frames 300, 320, and 417) when the cable went completely slack for several frames. The towline angle immediately in-

creased because the cable sagged back. The wing did not stall.

Accelerations.- The extreme normal accelerations recorded were 3 g and -1 g, more frequently 2.2 g and 0, but it is uncertain whether they occurred during the porpoising oscillations or in free flight (wing-overs). Since they are likely to have been negative when the tow force was highest (and vice versa), the actual load factors on the glider in tow must have been lower than the factors that would correspond to the normal component of the tow force plus the tail force necessary to balance it except where high tow forces lasted for definite periods. Considering this fact and estimating that the tail force may have to be almost half as large as the normal component of the tow force, it seems that wing loading equivalent to load factors of the order of 2.5 were probably reached during some of the test tows. On other flights, the maximum loads were much less.

Yawing.- In flight 8 an effort was made to yaw the glider while being towed. The yawing oscillations could be well followed by observing the movement of the terrain appearing on the movie films. These yawing maneuvers, although decidedly excessive, did not cause tow-force peaks as high as the other steep climbs of other flights. The yaw angles were not evaluated but it appears likely that lateral-force components of the order of a third of the tow force or half the gross weight may have occurred.

## II - AUTOMOBILE TOWED TESTS AT MUROC DRY LAKE, CALIFORNIA

### Equipment

The second group of tests were made on a glider named "Solvfuglen" (Danish for Silver Bird), identification number 12718, shown in figures 7 and 8. It was designed, owned, and operated by Volmer Jensen of Los Angeles. It is a conventional, braced, high-wing monoplane somewhat similar in features to the Cadet or to the standard Franklin Glider. It belongs in the so-called Utility or Secondary class. Its wing span is 36 feet and wing area, 166 square feet. Its gross weight in towed flight was close to 450 pounds, comprising:

| | Pounds |
|---|---|
| Weight empty . . . . . . . | 240 |
| Special equipment. . . . | 10 |
| Pilot. . . . . . . . . . . | 150 |
| Towline (approximately). | 50 |

The glider was towed from a 1930 Model A Ford car by 1,800 feet of 12-gage galvanized soft fence wire with approximately 100 feet of 3/8-inch snubber rope at the upper end. A hydraulic tensiometer shown in figure 9, consisting of a cylinder rubber-washer piston and a 2-1/2 inch Purox 500 pounds per square inch pressure gage was inserted in the upper end of the towline as shown in figure 10. The piston area was very nearly 1 square inch, so that the pressure gage was practically graduated in pounds tension. The instrument was calibrated by dead weights.

## Method

The flights were made on Muroc Dry Lake, a flat, dry lake bed in the desert suitable for many miles of auto towing in any direction. The tow car was driven by an experienced driver. Hand signals for slower and faster were arranged for careful control of the tow-car speed. The test flights were made at the occasion of two week-end expeditions, which were mostly devoted to training of student pilots.

On the first day, August 13, 1938, the weather was smooth and practically calm. The tow car was driven at 40 miles per hour. On the second day, September 2, 1938, a gusty wind of an average velocity estimated as 15 miles per hour was blowing and the car speed was held between 25 and 30 miles per hour.

All test flights (5 on the first day and 2 on the second) were made during the morning hours and while the sun was quite hot; no thermals of significance were encountered.

The glider was piloted by Volmer Jensen, Harry Haflin, and Larry Damenberg of Los Angeles. The first acted as instructor. The others had just completed a course of ap-

proximately 40 flights. They had been cautioned to climb slowly and gently and eventually reached altitudes of the order of 700 feet at indicated air speeds of the order of 40 miles per hour. Prior to releasing the towline, the climb was flattened and the towline eased. The release mechanism was so arranged that the tensiometer stayed on the glider. In no instance was porpoising or yawing encountered.

## Results and Discussion

In 7 of these 8 test flights, the tow force as read by the pilot on the pressure gage never exceeded 150 pounds. Only on one occasion with the stick pulled to the pilot's stomach, did the instrument register up to 200 pounds. The maximum slope of the top end of the cable against the fuselage axis was estimated as 60° on the basis of some snapshots taken from the wing.

As another example of remarkably low tow-line forces, the following experience may be worth mentioning. Volmer Jensen reports that on one occasion he made a flight holding the upper end of the tow rope in his hand instead of fastening it in the customary release hook. The tow car speed and acceleration were kept low until the glider was off the ground. Once in the air the climb was accomplished rapidly and an altitude of 200 feet was reached with a towline length of only 300 feet. The pilot reported that by bracing his feet against the rudder bar he found it easy to hold the line. He estimated the load could not have exceeded 100 pounds at any time. Another pilot, Henry Richmond, repeated the experience.

# III - PRELIMINARY AIRPLANE TOWED TESTS AT COMPTON, CALIFORNIA

## Equipment

The glider tested was the Briegleb Utility Model BG6, License No. NX21720, shown in figure 11. It is a straight high-wing monoplane, strut braced, single place; span, 32 feet 3 inches; aspect ratio, 8.9; gross weight, 370 pounds; cockpit cowled. It was piloted by Jack Ludowitz on the first test flight and by Fred Westphal on the second, both skilled and experienced glider pilots, although of very limited aircraft tow experience.

The glider was towed aloft by Fred Smith piloting a Curtiss Robin NC389K powered by a 185 horsepower Challenger engine. The indicated tow speed was held between 50 and 70 miles per hour. This pilot also had but very limited experience in glider towing operation. Only two previous tow flights had been made with the same equipment during the same morning to test the flying qualities of the glider. No difficulty was experienced and the towing operations, including the dropping and retrieving of the towline, were carried out without any interference with the private flying activities going on at the airport.

The towline consisted of 400 feet of 1/4-inch Manila rope attached to the tow plane's tail-wheel fork by means of quick release that could be operated from the airplane cockpit. A rear-vision mirror was mounted on one of the struts of the airplane so the tow pilot could see the glider provided that the latter trailed well.

The tow force was indicated by a Jensen hydraulic dynamometer, which was inserted as a tension link between the rear end of the towline and the nose hook of the glider. This dynamometer consisted of a hydraulic piston actuating a 500-pound pressure gage like the one used in some of the tests described in part II. This dynamometer had been recently calibrated in a Baldwin-Southwark testing machine in 50-pound increments with the following results:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Indicated | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 lb./sq.in. |
| True | 33 | 88 | 146 | 205 | 265 | 320 | 379 | 440 | 497 | 556 (±2 lb.) |

A 16-mm motion picture camera was mounted on an outrigger from the wing of the glider to photograph the pressure-gage dial of the dynamometer, as shown in figure 12. Vibrations blurred some of the exposures but most of them were legible to the nearest 10 pounds. The camera could be started by the glider pilot pulling on a string and it would then run for a maximum duration of 40 seconds. The camera was also meant to photograph the air-speed meter and the towline angle. Data from neither could be evaluated from the film, however, because the sun glare blotted out the hand and dial of the air-speed indicator and perspective caused the towline angle to appear too much foreshortened. No longer outrigger was available to move the camera more squarely abreast the dynamometer. The camera speed was approximately 20 frames per second.

The weather was bright and hot with some thermal activity, small, low scattered clouds forming near the coast. There was a strong, gusty west wind.

The tow flights to 4,000 feet took some 20 minutes each, but only a fraction of a minute was covered by each film during the straightaway climb shortly after the take-off.

Results and Discussion

The tensiometer indications were read from the film frame by frame and converted into forces according to the calibration curve. The results plotted against time are shown in figure 13.

According to these observations, the tow force averaged approximately 65 pounds. Several peaks reach 100 pounds and the highest one, 130 pounds. Fluctuations are of two types, very short ones lasting only a fraction of a second and slower ones favoring a frequency of the order of 4 seconds. These longer fluctuations are presumably the result of elevator maneuvers of the glider pilot attempting to correct variations from the desired trailing level.

These tow forces are remarkably low. Since they act essentially in the drag direction, their contribution to the stresses in the lift truss is undoubtedly insignificant. This result may be interpreted to confirm the common belieft that an aircraft tow, carefully executed, need not impose loads of any consequence for strength requirements of the glider. This result does not prove, however, that appreciable loads might not be encountered in towed flight maneuvers other than the straight climb during which the present films were taken or under other meteorological conditions or at higher tow speeds. These conditions are still to be explored.

## CONCLUSIONS

1. The present tests indicate that automobile tow forces depend greatly upon the towing and the piloting technique. Under favorable circumstances, they are insignificant and stay below the weight of the craft. Under conditions of deliberately rough maneuvers or simulating

extremely inexperienced handling, they reach values likely to produce load factors ranging from -1 g to 3 g.

2. It appears desirable in normal glider operation by automobile tow to use towlines of sufficient strength to assure a reasonable fatigue limit higher than 1-1/2 times the flight weight of the towed craft. A weak link at the top end of the line would seem to serve its purpose well if it fails at approximately twice the gross weight.

3. The conditions governing porpoising and means to avoid it would make a worth-while subject for a specific investigation.

4. The maximum towing force during straight climbs with airplane tow was small as compared with those resulting from other types of tow. Further investigation is desirable to indicate the critical loads in airplane-towed flight.

The Soaring Society of America, Inc.,
November 1939.

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2. Kronfeld, R.: Die Bedeutung von Schleppflugmessungen für den Schulbetrieb. Der Segelflieger No. 3, Arbeiten & Mitteilungen d. Braunschweig. Institut f. Luftfahrtmesstechnik u. Flugmeteorologie, 1932.

3. Garbell, M.: Technische Erfahrungen mit dem Windenschlepp in den italienischen Segelflugschulen. Mitteilungsblatt no. 5, Int. Study Commission for Motorless Flight (ISTUS), Dec. 1937.

Table I - Test Flights Made with Cadet Type of Secondary Training Glider at Akron, Ohio, October 30, 1937

| Flight | Rate of climb (m/s) | Maneuvers | Air speed Average (m.p.h.) | Air speed Maximum (m.p.h.) | Tow speed (m.p.h.) | Maximum altitude (ft.) | Wind velocity (m.p.h.) | Number of frames taken | Maximum tow force P (lb.) | Maximum towline angle α (deg.) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Slow 1.5 | Porpoising at top | 46 | 52 | 35 | 500 | 12 W | 633 | 370 | 54 |
| 2 | Moderate 3.0 | Porpoising | 60 | 63 | 35 | 600 | 12 WNW | 550 | 600 | 56 |
| 3 | Steep 4.5 | Porpoising | 57 | 61 | 35 | 600 | 15 WNW | 425 | 700 | 51 |
| 4 | Do 4.0 | | | 70 | 35 | 600 | 15 WNW | 50 | 710 | 59 |
| 5 | Do 4.5 | | | 60 | 40 | 700 | 15 W | 488 | 760 | 57 |
| 6 | Do 5.0 | Violent porpoising | 65 | | 40 | 800 | 20 W | 542 | 750 | 72 |
| 7 | Moderate 2.0 | | 65 | 69 | | | 15 W | | | |
| 8 | Do 2.0 | Yawing | 57 | 61 | 40 | 500 | 18 W | 479 | 600 | 44 |
| 9 | Steep 5.0 | Released under load | 58 | 61 | | 400 | 18 W | 53 | 800 | 47 |
| 10 | (a) | | | 44 | | | | | | |
| 11 | (a) | | | 65 | | | | | | |
| 12 | Moderate 4.0 | | 62 | 66 | 40 | 600 | 20 W | 338 | 630 | 49 |
| 13 | Do 3.5 | Moderate porpoising | 60 | 64 | 35 | 800 | 20 W | 541 | 530 | 51 |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | | | | | | |

[a]Towline failed in worn end of tensiometer cable.

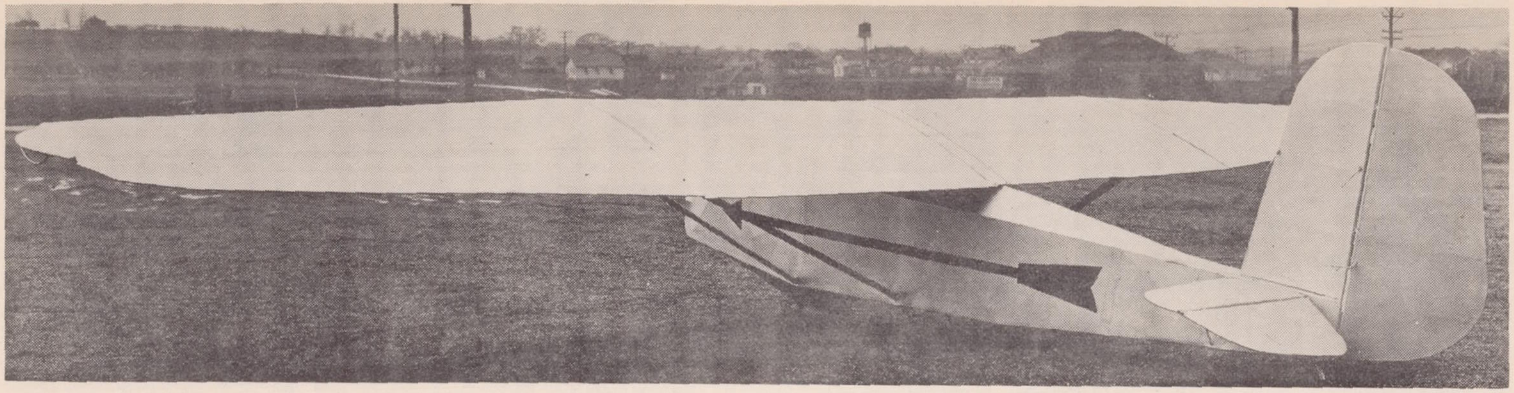

Figure 1.- Utility cadet type of glider used for group I of glider tow tests.

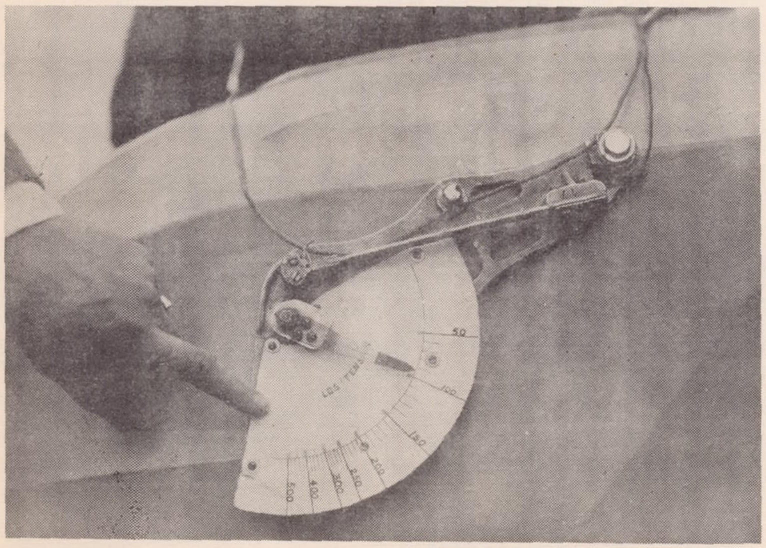

Figure 2.- Cable tensiometer of Goodyear Zeppelin type.

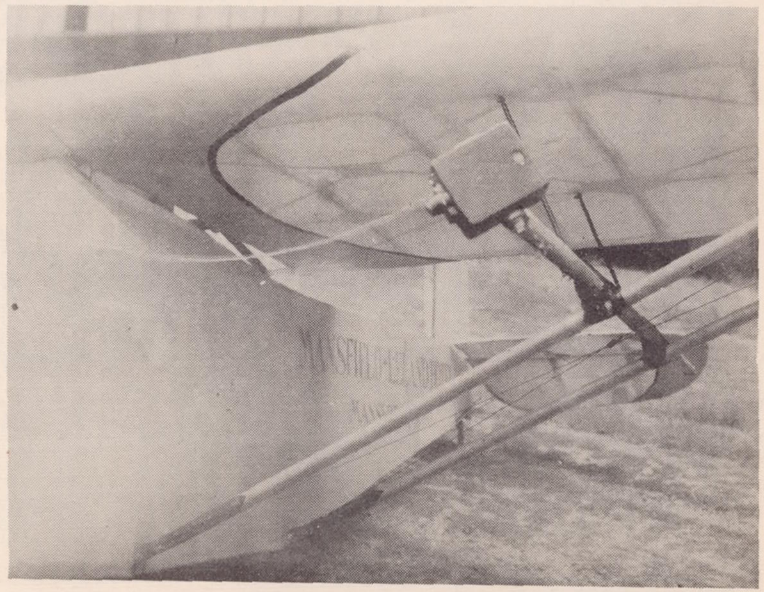

Figure 3.- Motion-picture camera installation for group I of glider tow tests.

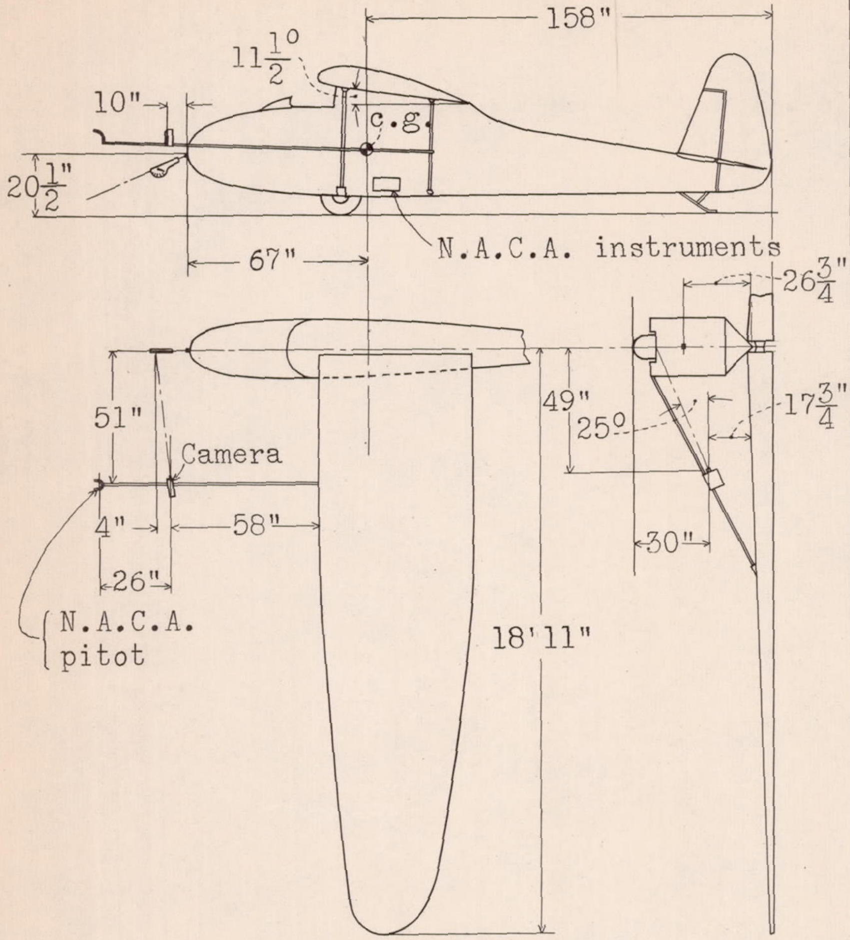


Figure 4.- Instrument arrangement used for group I of glider tow tests.

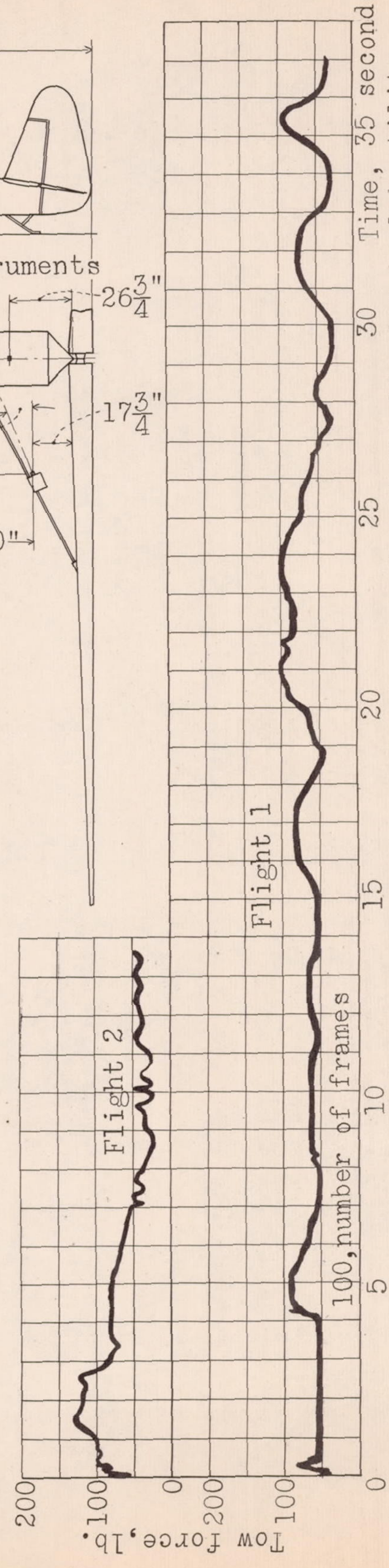


Figure 13.-Variation of glider towline force in airplane-towed flight of Briegleb utility glider.

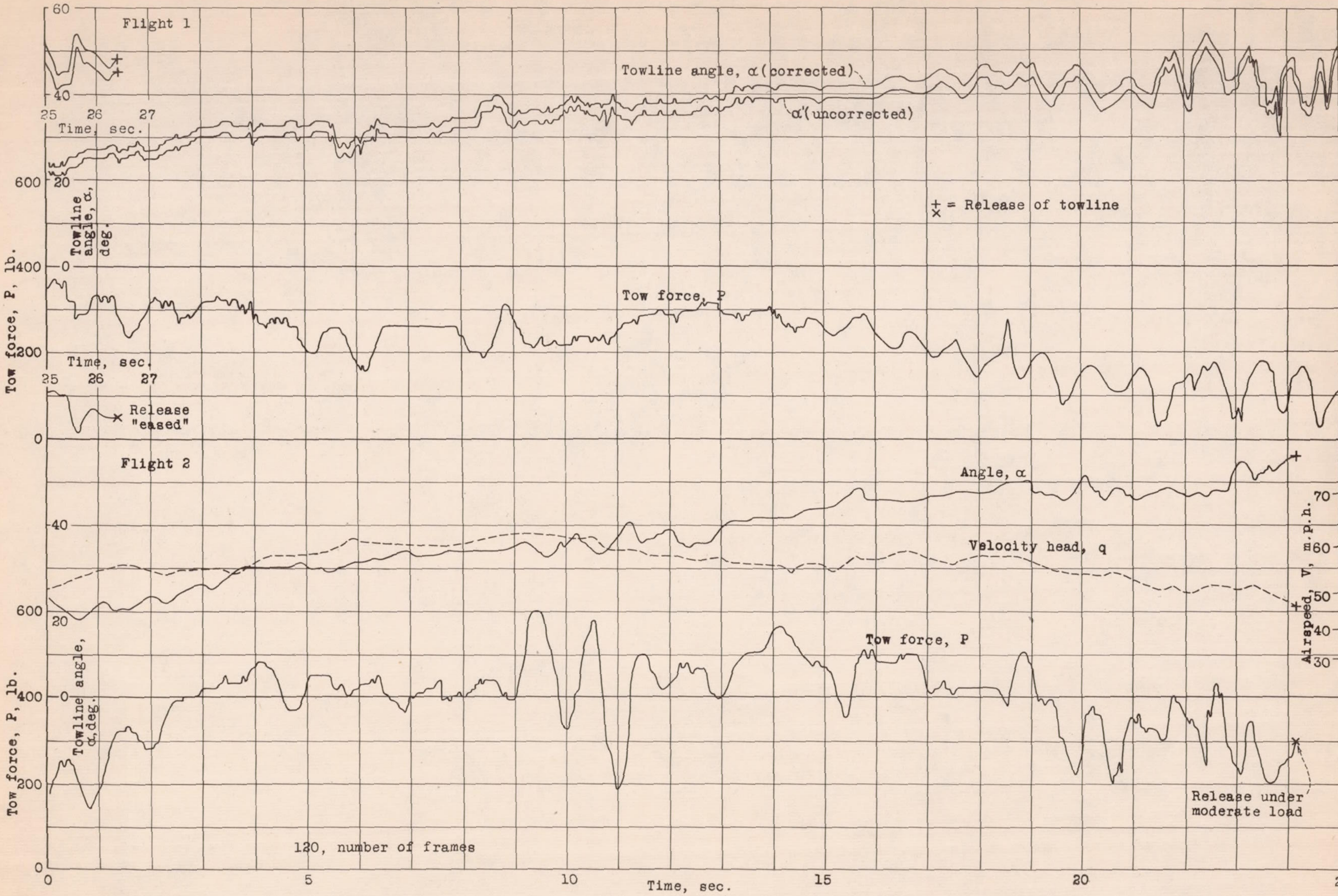


Figure 5, a to d.- Variation of glider towline force and angle.

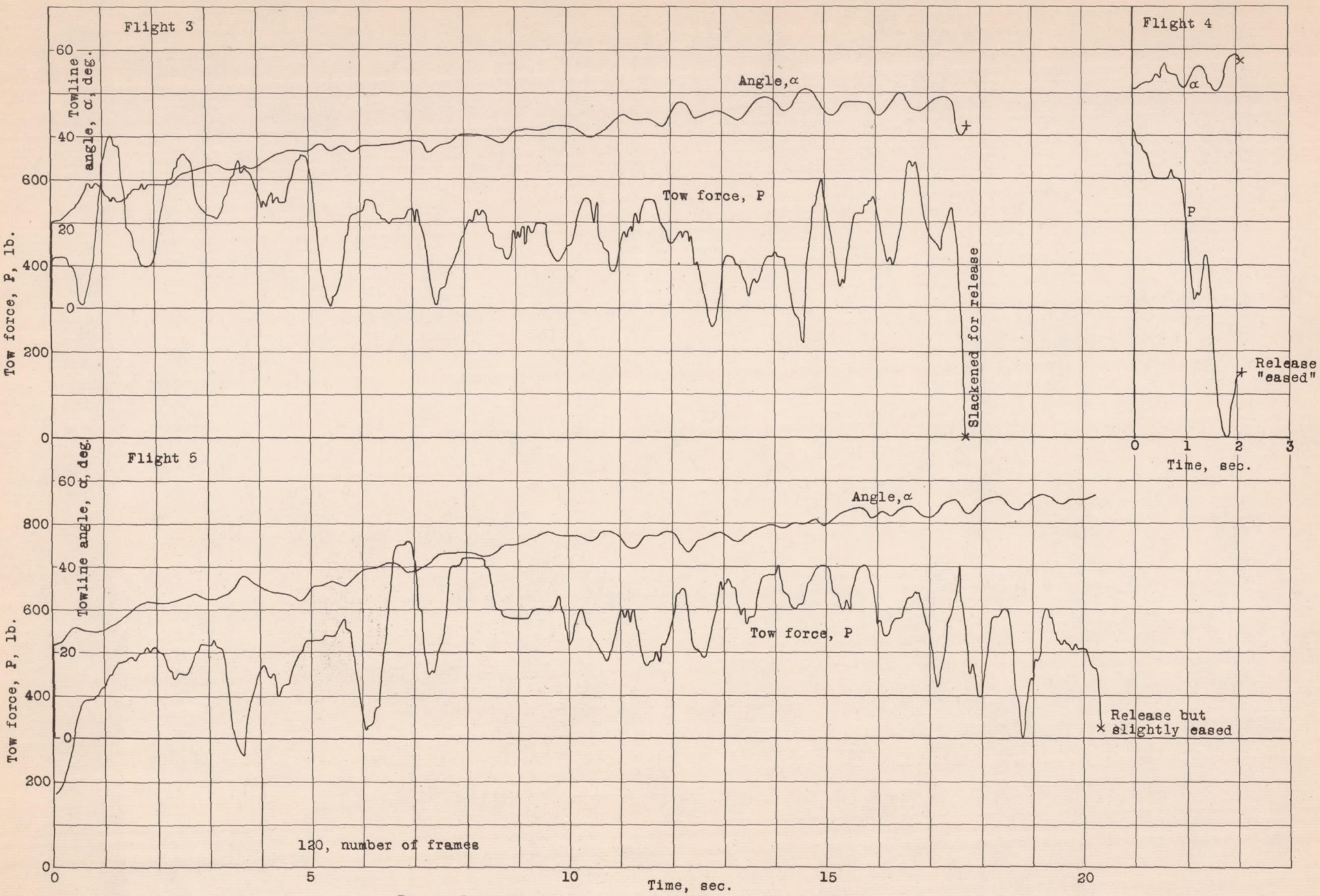


Figure 5, continued.

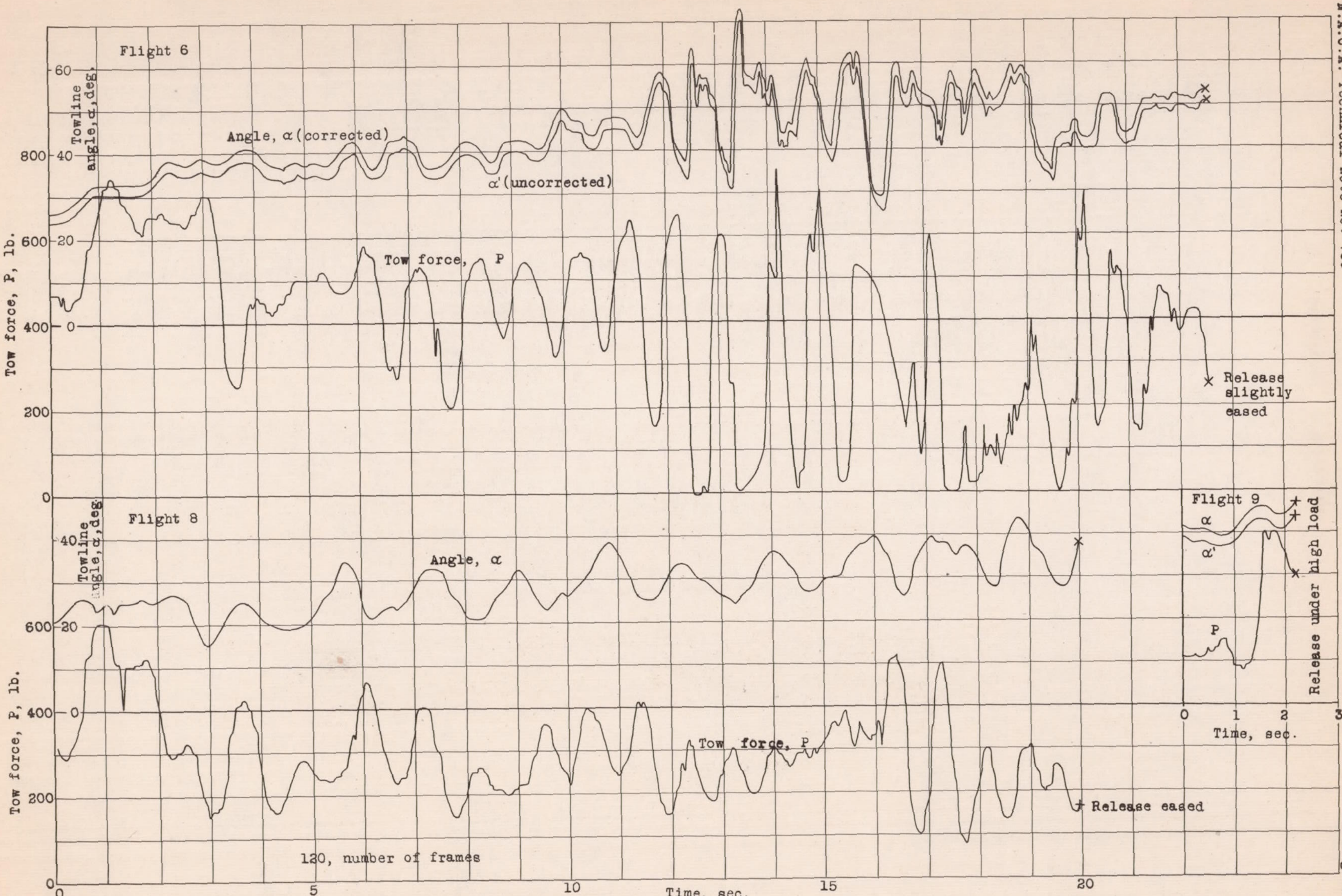


Figure 5, continued.

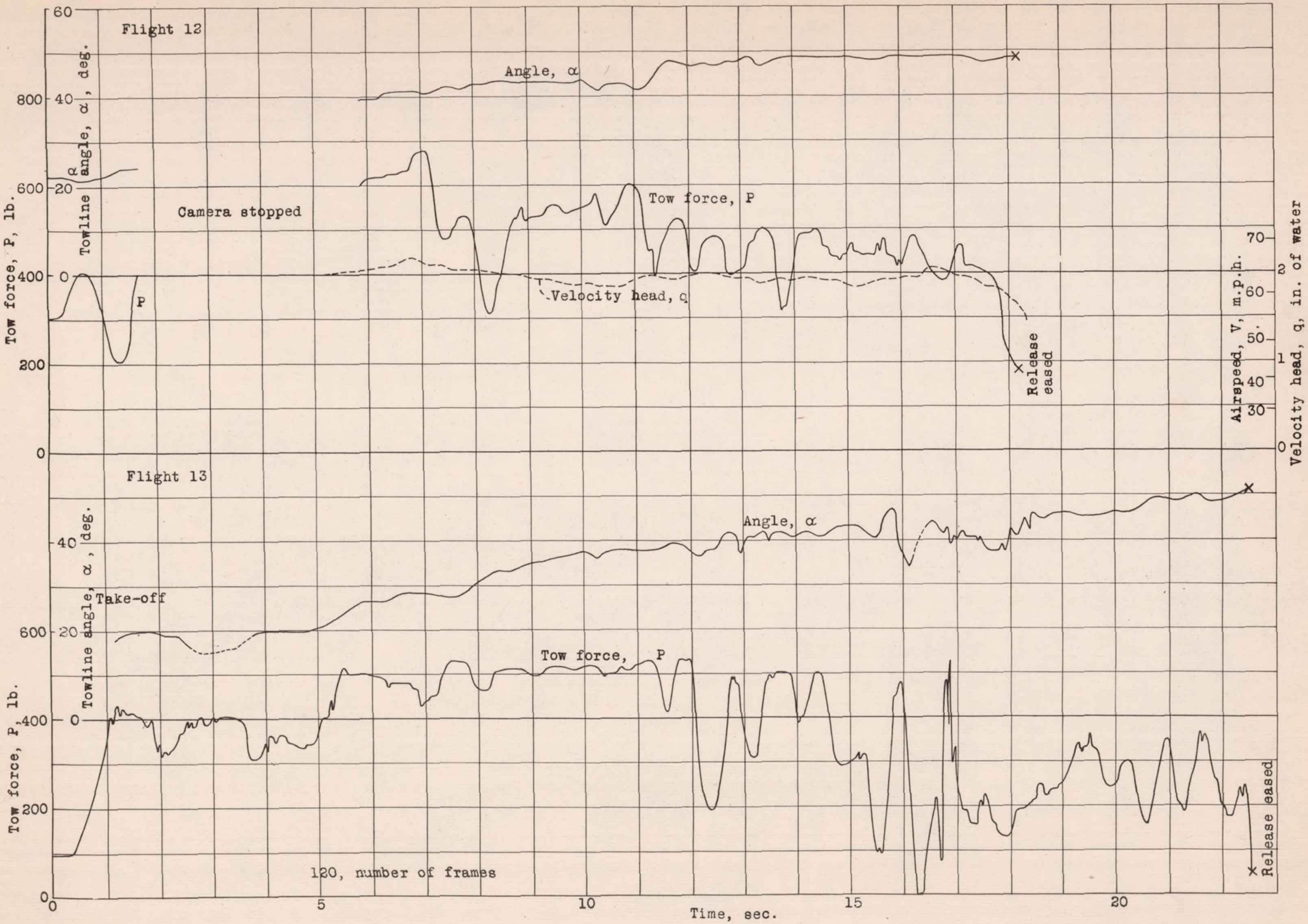


Figure 5, concluded.

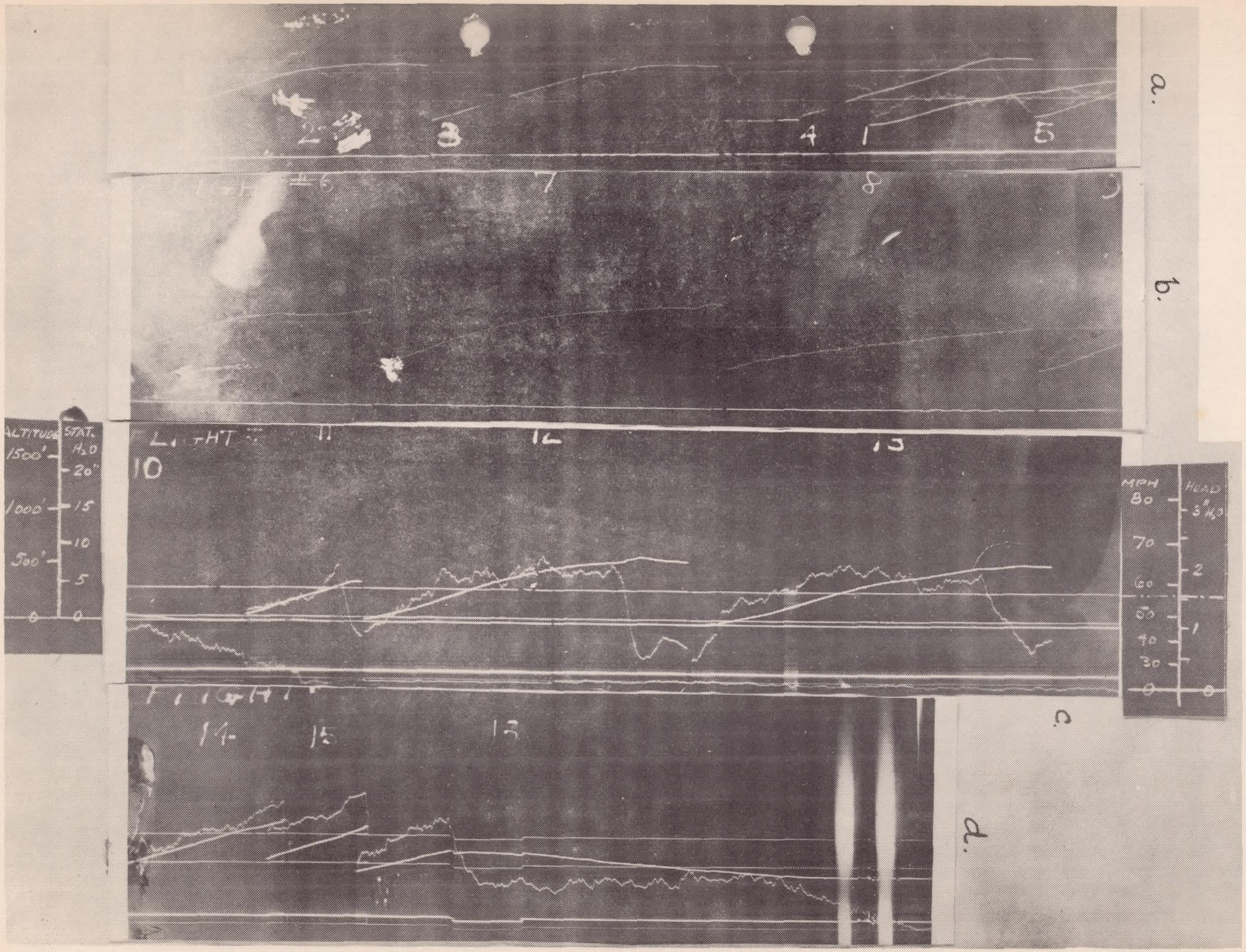


Figure 6.- N.A.C.A. velocity-head and statoscope records for towed cadet glider.

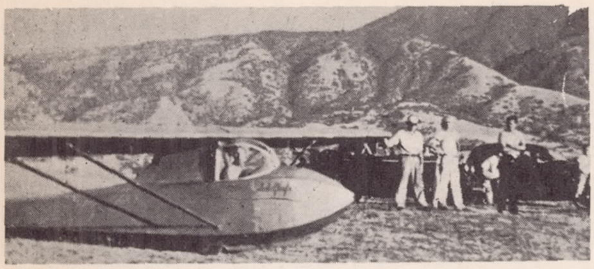

Figure 7.- Jensen utility glider Solvflugen used for group II of glider tow tests.

Figure 8.- Jensen utility glider Solvflugen used for group II of glider tow tests showing the tow-line release rope.

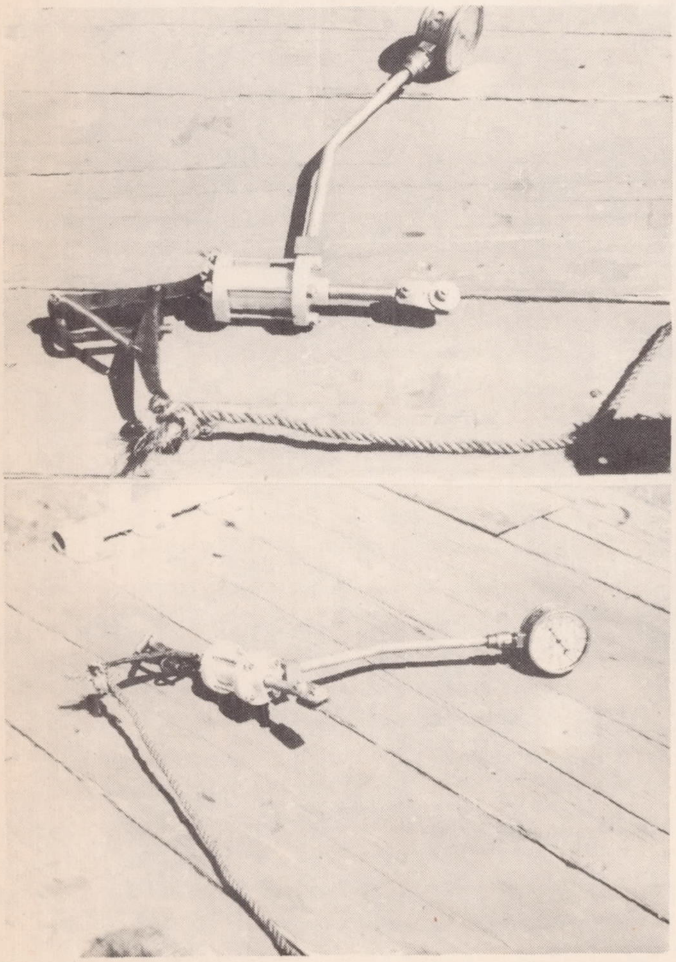

Figure 9.- Hydraulic tensiometer used for groups II and III of glider tow tests.

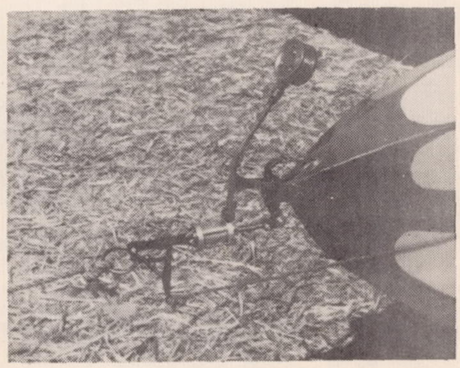

Figure 10.- Tensiometer installation for group II of glider tow tests.

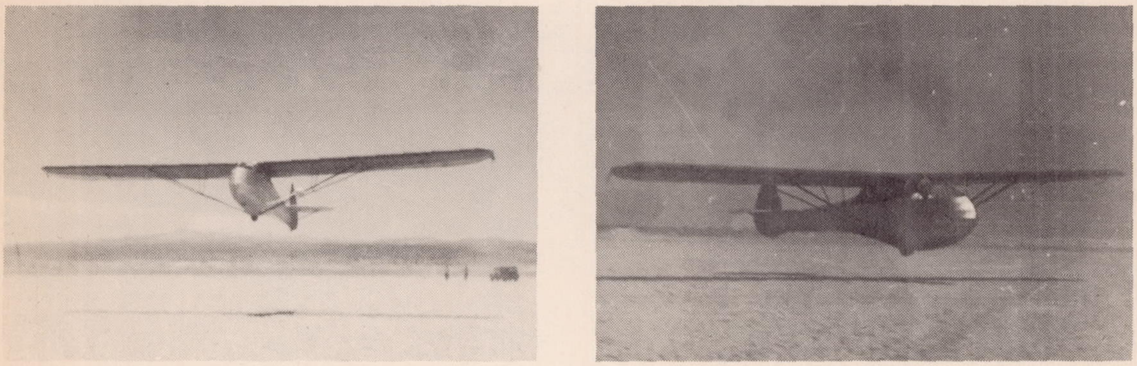

Figure 11.- Briegleb utility glider used for group III of glider tow tests.

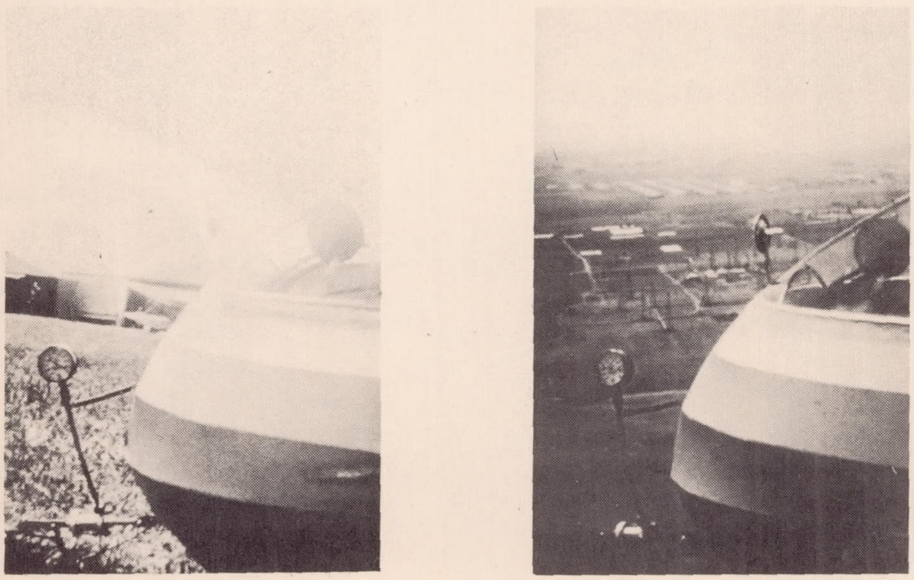

Figure 12.- Tensiometer installation for group III of glider tow tests.